ae8n

PCT/EP 00 / 12989
09/914091

Europäisches Patentamt

European Patent Office

Office européen des brevets

EP00/12983

REC'D 09 FEB 2001
WIPO PCT

4

# Bescheinigung Certificate Attestation

Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten europäischen Patentanmeldung überein.

The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

**Patentanmeldung Nr. Patent application No. Demande de brevet n°**

00204027.7

# PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)



Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

Hatten

I.L.C. HATTEN-HECKMAN

DEN HAAG, DEN
THE HAGUE, 04/01/01
LA HAYE, LE

[illegible]

# Blatt 2 der Bescheinigung
# Sheet 2 of the certificate
# Page 2 de l'attestation

Anmeldung Nr.:
Application no.: 00204027.7
Demande n°:

Anmeldetag:
Date of filing: 15/11/00
Date de dépôt:

Anmelder:
Applicant(s):
Demandeur(s):
Koninklijke Philips Electronics N.V.
5621 BA Eindhoven
NETHERLANDS

Bezeichnung der Erfindung:
Title of the invention:
Titre de l'invention:
Optical element

In Anspruch genommene Prioriät(en) / Priority(ies) claimed / Priorité(s) revendiquée(s)

| Staat: State: Pays: | Tag: Date: Date: | Aktenzeichen: File no. Numéro de dépôt: |
|---|---|---|

Internationale Patentklassifikation:
International Patent classification:
Classification internationale des brevets:
/

Am Anmeldetag benannte Vertragstaaten:
Contracting states designated at date of filing: AT/BE/CH/CY/DE/DK/ES/FI/FR/GB/GR/IE/IT/LI/LU/MC/NL/PT/SE/TR
Etats contractants désignés lors du depôt:

Bemerkungen:
Remarks:
Remarques:

Optical element.

~~The invention relates to an optical element for introducing a first wavefront~~ deviation in a first radiation beam of a first wavelength and a second wavefront deviation in a second radiation beam of a second wavelength different from the first wavelength, the optical element having a surface in the path of the first and second radiation beam. The invention also relates to an optical head for scanning an optical record carrier having an information layer, the head comprising a radiation source for generating a radiation beam, and an objective system for converging the radiation beam to a focus on the information layer, the optical head comprising such an optical element.

Progress in the field of optical recording results in the regular market introduction of new optical record carriers whith higher information densities. In general, such record carriers are designed for being scanned with a radiation beam of a wavelength and numerical aperture different from that used for scanning a previous generation of record carrier. It is desirable that a scanning device for the new record carriers can also scan the older record carriers. The scanning device must therefore be adapted such that it can provide two types of radiation beam, one for each type of record carrier. For example, a device suitable for scanning a record carrier of the so-called DVD type, provides a first radiation beam with a wavelength of 660 nm, a numerical aperture (NA) of 0.6 and a spherical aberration compensation for a record carrier substrate thickness of 0.6 mm. In order to scan previous generation record carriers of the so-called CD type, the device must also provide a second radiation beam having a wavelength of 785 nm, and NA of 0.45 and a spherical aberration compensation for a record carrier substrate thickness of 1.2 mm. The device is preferably provided with a single objective system for focussing the radiation beam onto the record carrier in order to keep the manufacturing costs low. Several solutions have been put forward to form two different radiation beams with a single objective system.

One solution is to divide the objective lens in a series of concentric annular areas, half of these zones having a spherical aberration compensation suitable for the new record carrier, the other zones having a spherical aberration compensation suitable for the old record carrier. Such an objective system is known from the International patent application no. 97/33277. A drawback of this lens is, that part of the light going through rings not having the

spherical aberration compensation appropriate for the record carrier being currently scanned is lost. This reduction of the efficiency of the light path of the optical head is disadvantageous in optical recorders, which require a large amount of radiation energy for writing information in the record carrier.

Another solution is disclosed in European patent application no. 0 936 604, in which a diffractive structure is arranged in the optical path of a first and second radiation beam having a first and second wavelength, respectively. The diffractive structure has no effect on the first radiation beam, which is used for scanning the new record carriers, but it forms a strong diffractive beam from the second beam making it suitable for scanning the old record carriers. Although the grating can be designed to yield 100% efficiency for both wavelengths, actual gratings never attain such a high efficiency.

The United States patent no. 5,835,283 discloses a third solution, in which an objective lens is divided in a plurality of annular areas. One half of the areas constitute a first lens surface, the other half of the areas constitute a second lens surface. Each of the lens surfaces transforms an incident radiation beam to a focus point, one focus point for each type of record carrier. As a consequence, approximately half of the radiation energy is focussed in one focus point, the other half is focussed in another focus point. Therefore, only half of the energy of the radiation beam is available for scanning a record carrier.

It is an object of the invention to provide an optical element that can be used in an optical scanning device and can transform an incident beam in a first or a second beam having different properties in dependence on the wavelength of the incident radiation beam, the optical element having a low radiation loss for both beams.

This object is achieved if, according to the invention, the surface of the optical element of the preamble comprises a phase structure in the form of annular areas, the areas forming a non-periodic pattern of optical paths of different length, the optical paths for the first wavelength forming the first wavefront deviation and the optical paths for the second wavelength forming the second wavefront deviation. Since the first and second wavelengths are different, the optical paths of each of the annular areas will be different for the first and second radiation beam. If the optical paths of the annular areas are properly chosen, the phase structure of the annular areas introduce a first wavefront deviation for the first wavelength and a second wavefront deviation for the second wavelength. Part of the design freedom of the phase structure resides in the fact that an extra optical path of an annular area of an integer number of first wavelengths does not change the first wavefront deviation but does change the second wavefront deviation.

It should be noted, that the phase structure according to the invention has a non-periodic pattern, and, therefore, does not form diffraction orders. As a consequence, the phase grating does not have the inherent losses of a grating. The optical element is therefore very suitable for use in an optical head that requires a change in wavefront in dependence on the wavelength of the radiation beam. The optical element can introduce the required wavefront changes in dependence on the wavelength of the radiation beam without appreciable loss of radiation energy.

In a preferred embodiment of the optical element the differences between the optical paths for the first wavelength are multiples of the first wavelength. The phase structure will not affect the first radiation beam, whereas it will introduce a wavefront deviation in the second radiation beam. Hence, the first wavefront deviation is zero.

A preferred embodiment of the optical element for interacting with a first radiation beam having a first wavelength and a second radiation beam having a different, second wavelength and introducing a wavefront deviation in the second radiation beam, the optical element having a surface in the path of the first and second radiation beam, the surface comprising a phase structure in the form of annular areas, the areas forming a non-periodic pattern of optical paths of different length, the optical paths for the second wavelength forming the wavefront deviation, wherein the differences between the optical paths for the first wavelength are multiples of the first wavelength and at least one of the multiples is larger than two. Although most wavefront deviations can be realised by using step heights between neighbouring areas equal to the first wavelength, the use of step heights of multiples of the first wavelength has the advantage that the number of areas necessary to form the wavefront deviation is reduced and the size of the areas increased. The larger areas facilitate the manufacture of the phase structure, the accuracy of which is limited by the cutting tools used for making the mould for the phase structure. The smaller areas resulting from step heights of one wavelength cannot be manufactured accurately using the current state of the art in cutting tools. The inaccuracy of a phase structure having these smaller areas result in loss of radiation due to scattering. The larger areas according to the invention have a relatively higher accuracy and, consequently, less loss of radiation. The less accurate approximation of the desired wavefront deviation caused by the larger steps reduces the quality of the spot formed by the radiation beam on the information layer of an optical record carrier. However, the overall performance of a scanning device using the phase structure having the large steps is better than that of a scanning device using the phase structure having the small steps.

When the difference between the first and the second wavefront deviation, or the wavefront deviation in the latter embodiment, is spherical aberration, the optical element can effect the change in wavefront required for changing the scanning between record carriers having different substrate thicknesses.

In a preferred embodiment the optical element is a lens, allowing the integration of the optical element with an objective lens. The phase structure is then applied to one of the surfaces of the lens. Such a lens, can be made by the known glass or plastic moulding or by the so-called replication technique, as can a plate-shaped optical element.

In a special embodiment of the optical element the difference between the first and the second wavefront deviation, or the wavefront deviation in the latter embodiment, is defocus. Defocus is a wavefront deviation that is quadratic in the radius of the radiation beam. The quadratic form modulo the second wavelength can be approximated by the wavefront steps introduced by the annular areas in the second radiation beam. The change in focal position caused by the defocus can advantageously be used in an optical head of a recorder. Switching of the radiation power between a high and a low level for writing and reading causes a small wavelength change of the radiation beam. The chromatic dispersion of common objective lenses causes a corresponding change in the axial position of the focus spot of the radiation beam. The relative slowness of focus servo systems causes a temporary defocus of the radiation beam on the record carrier when switching from reading power to writing power and vice versa. At shorter wavelengths the problem aggravates, because the defocus becomes larger due to the increased dispersion. If the optical element according to the invention is arranged in the radiation beam, the defocus introduced by the element in the radiation beam because of the change in wavelength can compensate the shift in focus position due to the dispersion of the objective system.

The difference between the first and the second wavefront deviation, or the wavefront deviation in the latter embodiment, is preferably spherochromatism. Spherochromatism is the spherical aberration caused by a lens when it is operated at a wavelength different from its design wavelength. The spherochromatism due to the lens can be compensated by an optical element according to the invention, when the phase structure of the optical element introduces the same amount of spherical aberration as a function of wavelength but with a different sign.

The difference between the two wavelengths for the optical elements forming a defocus or spherochromatism wavefront deviation is determined by the change in wavelength of a semiconductor laser. This difference is in general smaller than 20 nm. This should be contrasted with the first and second wavelengths for scanning different types of record carrier, which wavelengths differ by about 125 nm for the CD and DVD types of record carrier. ~~Whereas in the case of scanning of the two types of record carrier the compensation of the~~ wavefront is achieved for two discrete wavelengths, the compensation for the defocus and spherochromatism is achieved over a range of wavelengths, in which range the wavefront deviation introduced by the phase structure depends on the wavelength. In the latter case, the radiation beam of the first wavelength and the radiation beam of the second wavelength are generated by the same radiation source. The first wavelength may lie within the range over which the second wavelength may vary. The first wavelength may lie at one end of the range. The optical element may be designed for the first wavelength not to introduce a wavefront deviation and for a second wavelength differing from the first wavelength to introduce a wavefront deviation that depends on the difference between the two wavelengths. In a special embodiment the wavefront deviation is proportional to or depends linearly on the difference between the two wavelengths.

The phase structure for the compensation over a range of wavelengths may advantageously be constructed using one or more step heights of two or more times the first wavelength.

A second aspect of the invention relates to an optical head for scanning an optical record carrier having an information layer, the head comprising a radiation source for generating a first radiation beam having a first wavelength and a second radiation beam having a second wavelength, and an objective system for converging the first radiation beam and the second radiation beam to a focus on the information layer, wherein the optical head comprises an optical element according to the invention for introducing a first wavefront deviation in the first radiation beam and a second wavefront deviation in the second radiation beam.

A special embodiment of the optical head is suitable for scanning a first optical record carrier having a first information layer and a first transparent layer having a first thickness and second optical record carrier having a second information layer and a second transparent layer having a second thickness different from the first thickness. The objective system is adapted for converging the first radiation beam through the first transparent layer to a focus on the first information layer and the second radiation beam through the second transparent layer to a focus on the second information layer. The difference between the first

and the second wavefront deviation introduced by the optical element is spherical aberration, compensating the spherical aberration introduced by the thickness difference between the first and second record carrier.

Another embodiment of the optical head is suitable for scanning an optical record carrier having an information layer with the first or the second radiation beam. The difference between the first and the second wavefront deviation introduced by the optical element is defocus, compensating defocus caused by the dispersion of the objective system and the change in wavelength when switching from the first to the second radiation beam.

A third aspect of the invention relates to a device for scanning an optical record carrier having an information layer, the device comprising an optical head according to the invention and an information processing unit for error correction.

The objects, advantages and features of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings, in which

Figure 1 shows a scanning device according to the invention;

Figure 2 shows a cross-section of the optical element;

Figure 3 shows the wavefront aberration near the focal spot versus the normalised radius of the radiation beam;

Figure 4 shows a second embodiment of the scanning device according to the invention;

Figure 5 shows a cross-section of the wavefront of the radiation beam near the focal spot;

Figure 6 shows a cross-section of the phase structure used in the second embodiment.

Figure 1 shows a device 1 for scanning a first type of optical record carrier 2. The record carrier comprises a transparent layer 3, on one side of which an information layer 4 is arranged. The side of the information layer facing away from the transparent layer is protected from environmental influences by a protection layer 5. The side of the transparent layer facing the device is called the entrance face 6. The transparent layer 3 acts as a substrate for the record carrier by providing mechanical support for the information layer. Alternatively,

the transparent layer may have the sole function of protecting the information layer, while the mechanical support is provided by a layer on the other side of the information layer, for instance by the protection layer 5 or by a further information layer and a transparent layer connected to the information layer 4. Information may be stored in the information layer 4 of the record carrier in the form of optically detectable marks arranged in substantially parallel, concentric or spiral tracks, not indicated in the Figure. The marks may be in any optically readable form, e.g. in the form of pits, or areas with a reflection coefficient or a direction of magnetization different from their surroundings, or a combination of these forms.

The scanning device 1 comprises a radiation source that can emit a first and a second radiation beam 7 and 8 having different wavelengths. The radiation source shown in the Figure comprises two semiconductor lasers 9 and 10, emitting the radiation beam 7 and 8. A beam splitter 11, for example a semitransparent plate, combines the paths of the two beams 7 and 8 to a single optical path. The first radiation beam is used for scanning optical record carrier 2 of the first type. The second radiation beam is used for scanning optical record carriers of a second type. A second beam splitter 13 reflects the diverging radiation beam 12 on the optical path towards a collimator lens 14, which converts the diverging beam 12 into a collimated beam 15. The collimated beam 15 is incident on a transparent optical element 16, which modifies the wavefront of the collimated beam. The beam 17 coming from the optical element 16 is incident on an objective system 18. The objective system may comprise one or more lenses and/or a grating. The objective system 18 has an optical axis 19. The objective system 18 changes the beam 17 to a converging beam 20, incident on the entrance face 6 of the record carrier 2. The objective system has a spherical aberration correction adapted for passage of the radiation beam through the thickness of the transparent layer 3. The converging beam 20 forms a spot 21 on the information layer 4. Radiation reflected by the information layer 4 forms a diverging beam 22, transformed into a substantially collimated beam 23 by the objective system 18 and subsequently into a converging beam 24 by the collimator lens 14. The beam splitter 13 separates the forward and reflected beams by transmitting at least part of the converging beam 24 towards a detection system 25. The detection system captures the radiation and converts it into electrical output signals 26. A signal processor 27 converts these output signals to various other signals. One of the signals is an information signal 28, the value of which represents information read from the information layer 4. The information signal is processed by an information processing unit for error correction 29. Other signals from the signal processor 27 are the focus error signal and radial error signal 30. The focus error signal represents the axial difference in height between the spot 21 and the information layer 4. The

radial error signal represents the distance in the plane of the information layer 4 between the spot 21 and the centre of a track in the information layer to be followed by the spot. The focus error signal and the radial error signal are fed into a servo circuit 31, which converts these signals to servo control signals 32 for controlling a focus actuator and a radial actuator respectively. The actuators are not shown in the Figure. The focus actuator controls the ~~position of the objective system 18 in the focus direction 33, thereby controlling the actual~~ position of the spot 21 such that it coincides substantially with the plane of the information layer 4. The radial actuator controls the position of the objective lens 18 in a radial direction 34, thereby controlling the radial position of the spot 21 such that it coincides substantially with the central line of track to be followed in the information layer 4. The tracks in the Figure run in a direction perpendicular to the plane of the Figure.

The device of Figure 1 is adapted to scan also a second type of record carrier 40. This record carrier comprises a thicker transparent layer 41 than the record carrier 2, an information layer 42, a protective layer 43 and an entrance face 44. The device uses the second radiation beam 8 for scanning the information plane 42. The NA of this radiation beam may be adapted to obtain a converging beam 45 having an NA suitable for forming a focal spot 47 for scanning the information layer 42. The spherical aberration compensation of the objective system 18 is not adapted to the thickness of the transparent layer 41. However, the optical element 16 introduces a wavefront deviation when the second radiation beam passes through it, the wavefront deviation having the form of spherical aberration. The amount of spherical aberration in the radiation beam 46 incident on the objective system is chosen such, that the combined spherical aberration introduced in the radiation beam by the optical element 16 and the objective system 18 compensates the spherical aberration incurred by the radiation beam in passing the transparent layer 41.

Figure 2 shows a cross-section of the optical element 16. The optical element comprises a transparent plate 50, one surface of which is a phase structure, which is rotationally symmetric around the optical axis 19. The phase structure has a central area 51 and four concentric annular areas 52, 53, 54 and 55. The annular areas 52 and 54 are rings with a height of $h_1$ above the height of the central area 51. The annular area 53 is a ring with a height of $h_2$ above the height of the central area. The height of the areas in the Figure is exaggerated with respect to the thickness and radial extent of the plate 50. The annular area 55 has the same height as the central area 51. The heights $h_1$ and $h_2$ are each an integer multiple of a height h given by

$$h = \frac{\lambda_1}{n_1 - 1}$$

where $\lambda_1$ is the first wavelength and n1 is the refractive index of the material of the annular area at the wavelength $\lambda_1$. Since each of the annular zones introduces a phase change of a multiple of $2\pi$ in the first radiation beam, the phase structure does not change the wavefront of the first radiation beam.

The second radiation beam has a wavelength $\lambda_2$ different from $\lambda_1$, the wavefront of which will be affected by the optical element, because the phase changes introduced by the annular areas are not equal to multiples of $2\pi$. The material of the annular areas is Diacryl, having a refractive index $n_1$ of 1.564 for $\lambda_1$ equal to 660 nm and a refractive index $n_2$ of 1.559 for $\lambda_2$ equal to 785 nm. Table I shows the phase changes $mh(n_2-1)/\lambda_2$ module $2\pi$ for values of m from 1 to 6.

| m | Phase for $\lambda_2$ (mod $2\pi$)(rad) |
|---|---|
| 1 | 5.235 |
| 2 | 4.188 |
| 3 | 3.142 |
| 4 | 2.094 |
| 5 | 1.047 |
| 6 | 0.0 |

Table I

The heights and radial extent of the annular areas must be chosen to introduce an amount of spherical aberration equal to the difference between that introduced in the converging beam 45 having a wavelength $\lambda_2$ and an NA of 0.45 by a transparent layer of 1.2 mm and the compensation introduced by the objective system 18. This can be achieved, if the value of m for the areas 51 to 55 is taken equal to 0, 5, 4, 5 and 0, respectively, and the radial extent of the annular areas 52 to 55 expressed as a normalised radius of the second radiation beam at the axial position of the optical element 26 is from 0.33 to 0.48, 0.48 to 0.89, 0.89 to 0.97 and 0.97 to 1.00, respectively. It should be noted, that the shape of the phase structure is concave in parts where the introduced wavefront deviation is convex.

The stepped wavefront deviation introduced by the optical element is an approximation of the desired spherical aberration. Figure 3 shows the wavefront aberration near the focal spot 47 in wavelengths $\lambda_2$ versus the normalised radius of the radiation beam. The drawn line 60 represents the wavefront aberration for the case the optical element 16 does not introduce a wavefront deviation in the second radiation beam. The dotted line 61 represents the remaining wavefront aberration for the case the optical element has the above-mentioned phase structure. The full-width-at-half-maximum (FWHM) of the point spread function of the focal spot 21 for scanning the record carrier 1 of the first type is equal to 0.57 μm. The FWHM of the focal spot 47 for scanning the record carrier 40 of the second type is equal to 0.90 μm, i.e. only 0.2% larger than the focal spot formed by an objective system designed specifically for scanning the record carrier 40 with an NA of 0.45.

If the NA of the second radiation beam is increased from 0.45 to 0.50, the amount of spherical aberration to be compensated increases and the number of annular areas may be increased from four to seven with successive heights of 5h, 4d, 3h, 2h, 3h, 4h and 5h. The focal spot 21 has again an FWHM of 0.57 μm, and the focal spot 47 an FWHM of 0.81 μm, being equal to the FWHM of the focal spot formed by an objective system specifically designed for scanning the record carrier 49 with an NA of 0.50.

If the first radiation beam converges on the record carrier 2 with a larger numerical aperture than the second radiation beam on the record carrier 40, the optical element will have a correspondingly larger diameter, and the phase structure will be arranged on that part of the optical element corresponding to the numerical aperture of the second radiation beam. The annular ring around the phase structure may be left transparent for the first and second wavelength or may be provided with a wavelength-selective filter that passes only the first wavelength.

Figure 4 shows an embodiment 70 of the scanning device according to the invention for reading and writing an a high-density record carrier 71. The record carrier comprises a writeable information layer 72, protected on the radiation-incident side by a 100 μm thick transparent layer 73. A substrate 74 on the other side of the information layer provides mechanical strength to the record carrier. The device 70 comprises a control circuit 75 for controlling the output power of a radiation source 76, in particular between a read level and a higher write level. The radiation source is a semiconductor laser providing a first diverging radiation beam 77 at a wavelength of 400 nm when operating at the read level and a second radiation beam 77' at a wavelength of 402 nm when operating at the write level.

Alternatively, the wavelength at the read level is 402 nm and at the write level 400 nm. A beam splitter 78 reflects the diverging radiation beam 77 towards a collimator lens 79, which converts the diverging beam 77 into a collimated beam 80. The collimated beam 80 is incident on an objective system 81, comprising a first lens 82 and a second lens 83, and having an NA of 0.85. The objective system 81 has an optical axis 84. The objective system 81 changes the beam 80 to a converging beam 85, incident on the record carrier 71. The objective system has a spherical aberration correction adapted for passage of the radiation beam through the thickness of the transparent layer 73. The converging beam 85 forms a focal spot 86 on the information layer 72. Radiation reflected by the information layer 72 forms a diverging beam, transformed into a substantially collimated beam 87 by the objective system 81 and subsequently into a converging beam 88 by the collimator lens 79. The beam splitter 78 separates the forward and reflected beams by transmitting at least part of the converging beam 88 towards a detection system 89. The detection system captures the radiation and converts it into electrical output signals 90. A signal processor 91 converts these output signals to various other signals, similar to the signal processor 27 in Figure 1.

The dispersion of a specific design of the objective system 81 causes a defocus of 0.37 μm, corresponding to 122 mλ RMS, when the wavelength of the radiation beam 80 changes by Δλ equal to 2 nm on changing the radiation power from the reading level to the writing level. It should be noted that the focal depth $\lambda/(2NA^2)$ is only 0.28 μm . Figure 5 shows a cross-section of the wavefront of the radiation beam near the focal spot 86 as a function of the normalised radius in the radiation beam; the defocus is represented by line 95.

The objective system is achromatized by providing the device 70 with a phase structure 97 according to the invention. The phase structure is arranged on the surface 86 of the first lens 82 of the objective system, being the surface on which the collimated beam 80 is incident. The phase structure comprises five annular areas and a central area, the height of which increases stepwise from the centre of the structure to the outer radius of the radiation beam. Figure 6 shows a cross-section of the phase structure from its centre on the optical axis 84 to the outer radius at 1.5 mm. The structure is made of Diacryl and applied to the body of the lens 82 by the replication technique. The phase structure may be incorporated in the aspheric mould for making the aspheric surface 86. The refractive index $n$ of Diacryl is equal to 1.59501 at a wavelength of 400 nm. The radii of the annular areas, the height of the each area and the relative phase of the radiation beam after passage through the area are given in Table II.

| begin area (mm) | end area (mm) | height m*h (μm) | m | relative phase (radians) |
|---|---|---|---|---|
| 0.0 | 0.5 | 0 | 0 | 0 |
| 0.5 | 0.73 | 4.7031 | 7 | -0.2436 |
| 0.73 | 0.99 | 12.7656 | 19 | -0.6612 |
| 0.99 | 1.23 | 23.5156 | 35 | -1.2180 |
| 1.23 | 1.40 | 34.9374 | 52 | -1.8096 |
| 1.40 | 1.50 | 45.0155 | 67 | -2.3316 |

Table II

The values in Table II, calculated for a phase structure on a plane, will be slightly modified, if the obliqueness of the lens surface is taken into account. The height of each area is an integral multiple m of a height h equal to 0.6719 μm, being the height that causes a relative phase of $2\pi$ for the wavelength of 400 nm. Hence, the phase structure does not affect the wavefront of the first radiation beam 77. When the wavelength changes by $\Delta\lambda$, a step height of h introduces a relative phase $\phi$ equal to

$$\phi = 2\pi\left(\frac{\lambda(n+\Delta n-1)}{(\lambda+\Delta\lambda)(n-1)}-1\right) \approx 2\pi\frac{\Delta\lambda}{\lambda}$$

Since $\Delta n/\Delta\lambda = -1.7\ 10^{-4}\ \mathrm{nm}^{-1}$ for Diacryl, the effect of the change $\Delta n$ of the refractive index on $\phi$ is an order of magnitude smaller than the effect of the wavelength change. The right-most column of Table II gives the relative phases calculated according to the equal sign. The stepped wavefront introduced by the phase structure in the radiation beam 77' is shown in Figure 5 as line 96. The wavefront approximates the defocus 95 caused by the dispersion of the objective system 81 but with different sign. Since the stepped wavefront is an approximation, the compensation of the defocus will not be perfect, and a rest wavefront error of 23 mλ RMS of higher order terms remains in the radiation beam 85 near the focal spot 86. The phase structure 97 compensates the change in position of the focal spot due to the dispersion of the objective system when changing from read level to write level power, thereby reducing the RMS wavefront error from 122 to 23 mλ.

The dispersion compensation of the phase structure allows the use of higher-dispersion glass for the lenses of the objective system, which are in general cheaper. Since the

phase structure can be incorporated in the mould for the lens 82, the phase structure does not add to the cost of the scanning device.

The optical element comprising the phase structure may be used to achromatize an optical system. For example, when the objective system comprises a grating, the phase structure can be used to compensate the dispersion of the grating. Although the described embodiments of the optical element are used in transmission, it will be clear that the invention is also applicable to optical elements used in reflection.

CLAIMS:

1. An optical element for introducing a first wavefront deviation in a first radiation beam of a first wavelength and a second wavefront deviation in a second radiation beam of a second wavelength different from the first wavelength, the optical element having a surface in the path of the first and second radiation beam, characterised in that the surface comprises a phase structure in the form of annular areas, the areas forming a non-periodic pattern of optical paths of different length, the optical paths for the first wavelength forming the first wavefront deviation and the optical paths for the second wavelength forming the second wavefront deviation.

2. Optical element according to Claim 1, wherein the differences between the optical paths for the first wavelength are multiples of the first wavelength.

3. Optical element according to Claim 1 or 2, wherein the difference between the first and the second wavefront deviation is spherical aberration.

4. Optical element according to Claim 1 or 2, wherein the difference between the first and the second wavefront deviation is defocus.

5. An optical element for interacting with a first radiation beam having a first wavelength and a second radiation beam having a different, second wavelength and introducing a wavefront deviation in the second radiation beam, the optical element having a surface in the path of the first and second radiation beam, the surface comprising a phase structure in the form of annular areas, the areas forming a non-periodic pattern of optical paths of different length, the optical paths for the second wavelength forming the wavefront deviation, characterised in that the differences between the optical paths for the first wavelength are multiples of the first wavelength and at least one of the multiples is larger than two.

6. Optical element according to Claim 5, wherein the wavefront deviation is spherical aberration.

7. Optical element according to Claim 5, wherein the wavefront deviation is defocus.

8. Optical element according to Claim 5, wherein the wavefront deviation is spherochromatism.

9. An optical element for interacting with a first radiation beam having a first wavelength and a second radiation beam having a different, second wavelength and introducing a wavefront deviation in the second radiation beam, the optical element having a surface in the path of the first and second radiation beam, the surface comprising a phase structure in the form of annular areas, the areas forming a non-periodic pattern of optical paths of different length, the optical paths for the second wavelength forming the second wavefront deviation, characterised in that the wavefront deviation is proportional to the difference between the first wavelength and the second wavelength.

10. Optical element according to any of the previous Claims, wherein the element is a lens.

11. An optical head for scanning an optical record carrier having an information layer, the head comprising a radiation source for generating a first radiation beam having a first wavelength and a second radiation beam having a second wavelength, and an objective system for converging the first radiation beam and the second radiation beam to a focus on the information layer, characterised in that the optical head comprises an optical element according to any of the previous Claims for introducing a first wavefront deviation in the first radiation beam and a second wavefront deviation in the second radiation beam.

12. Optical head according to Claim 11 for scanning a first optical record carrier having a first information layer and a first transparent layer having a first thickness and second optical record carrier having a second information layer and a second transparent layer having a second thickness different from the first thickness, wherein the objective system is adapted for converging the first radiation beam through the first transparent layer to a focus on the first information layer and the second radiation beam through the second transparent layer to a focus on the second information layer, and the difference between the first and the second wavefront deviation introduced by the optical element is spherical aberration.

13. Optical head according to Claim 11 for scanning an optical record carrier having an information layer with the first radiation beam or the second radiation beam, wherein the difference between the first and the second wavefront deviation introduced by the optical element is defocus.

14. A device for scanning an optical record carrier having an information, the device comprising an optical head according to Claim 11 and an information processing unit for error correction.

ABSTRACT:

An optical element (16) introduces a first wavefront deviation when a first radiation beam having a first wavelength passes through it and a second wavefront deviation when a second radiation beam having a second wavelength different from the first wavelength passes through it. One surface of the optical element comprises a phase structure in the form of annular areas (52, 53, 54, 55), the areas forming a non-periodic pattern of optical paths of different length. The optical paths for the first wavelength form the first wavefront deviation and the optical paths for the second wavelength form the second wavefront deviation.

Figure 2

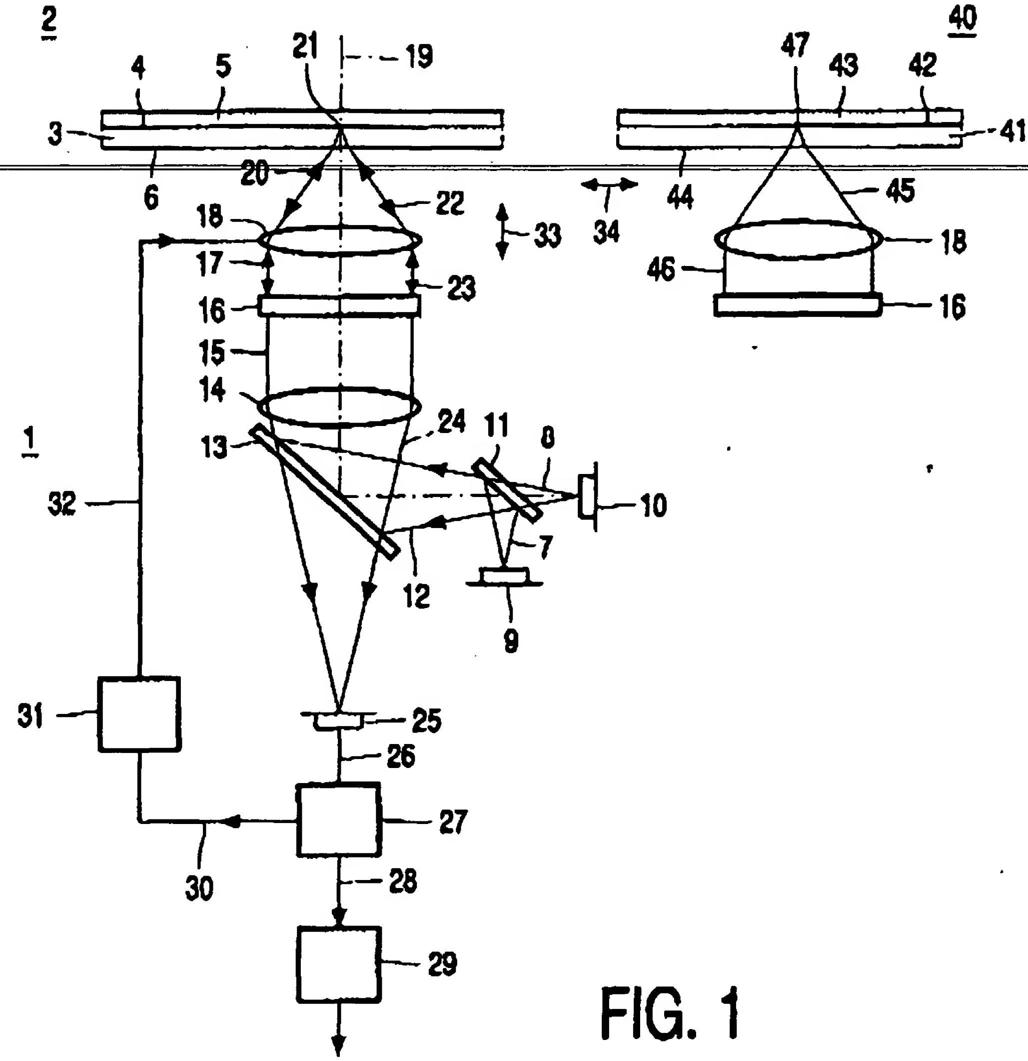
2
40
21
19
47
43
42
4
5
3
41
6
20
22
44
45
34
33
18
17
23
16
46
15
14
24
11
8
13
1
10
32
7
12
9
31
25
26
27
30
28
29

FIG. 1

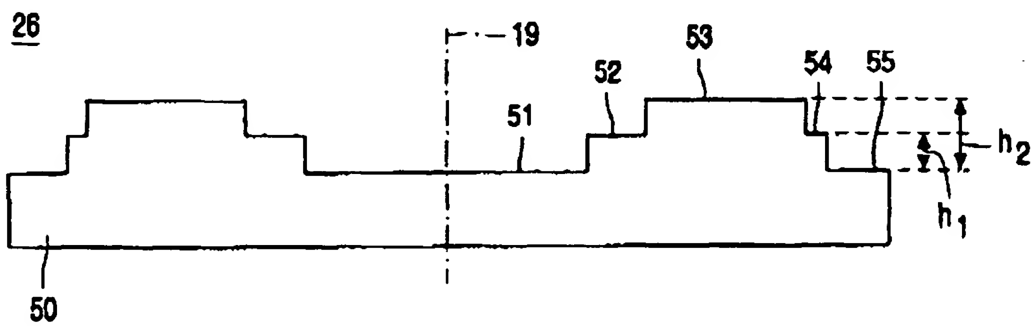
26
19
53
52
54
55
51
h2
h1
50

FIG. 2

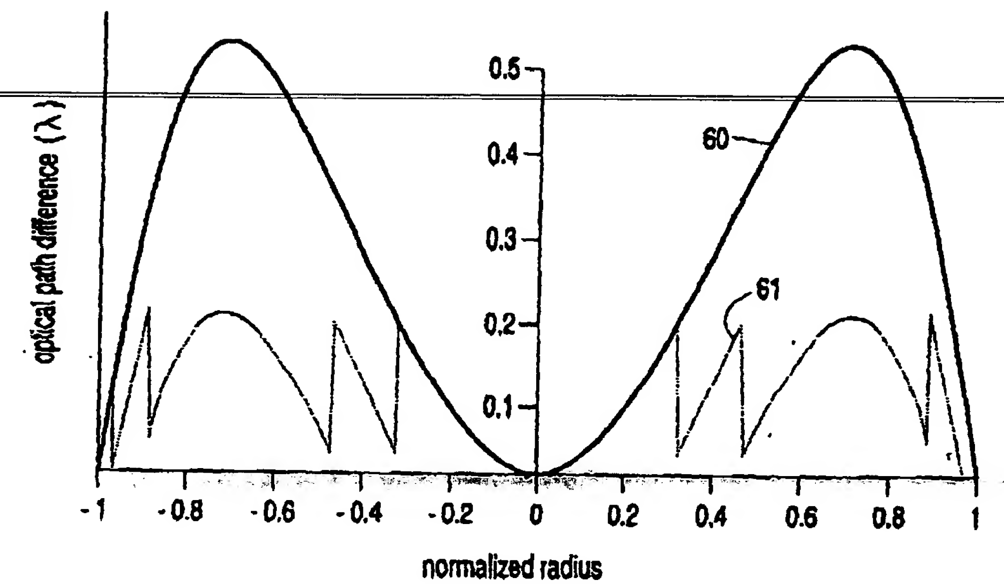
optical path difference (λ)
0.5
0.4
0.3
0.2
0.1
60
61
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
normalized radius

FIG. 3

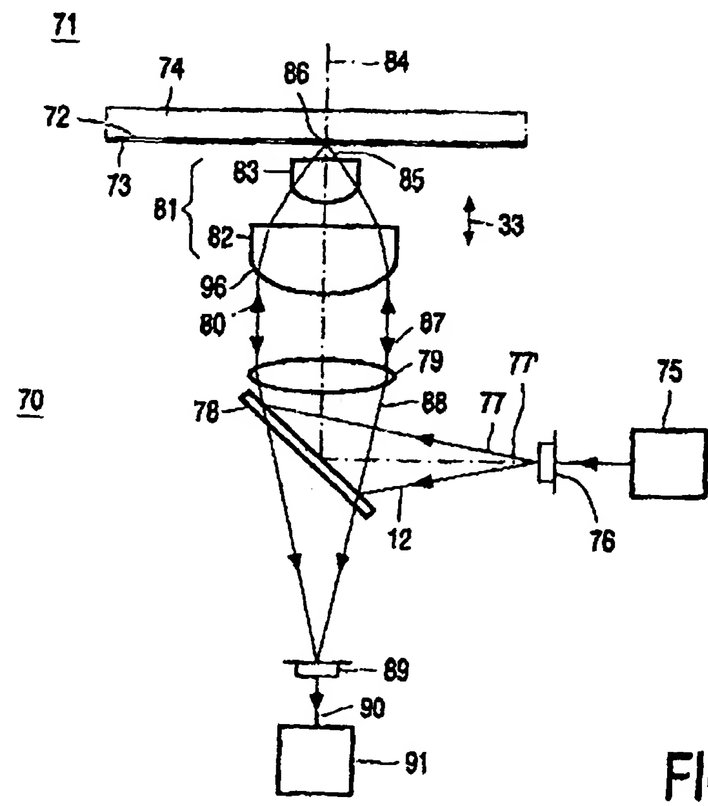
71
74
86
84
72
73
83
85
81
82
33
96
80
87
79
77'
75
70
78
88
77
12
76
89
90
91

FIG. 4

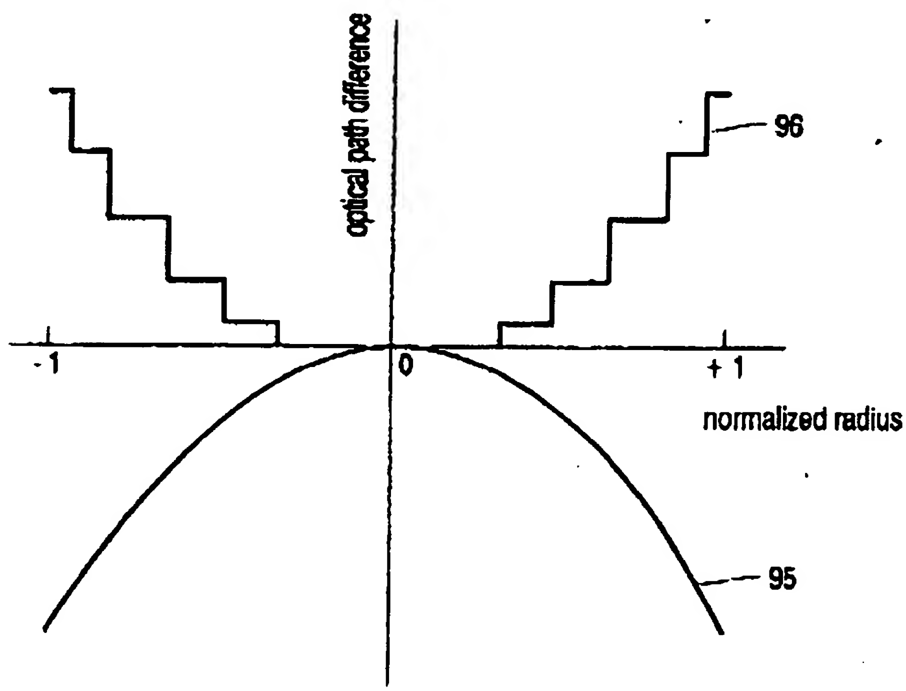


FIG. 5

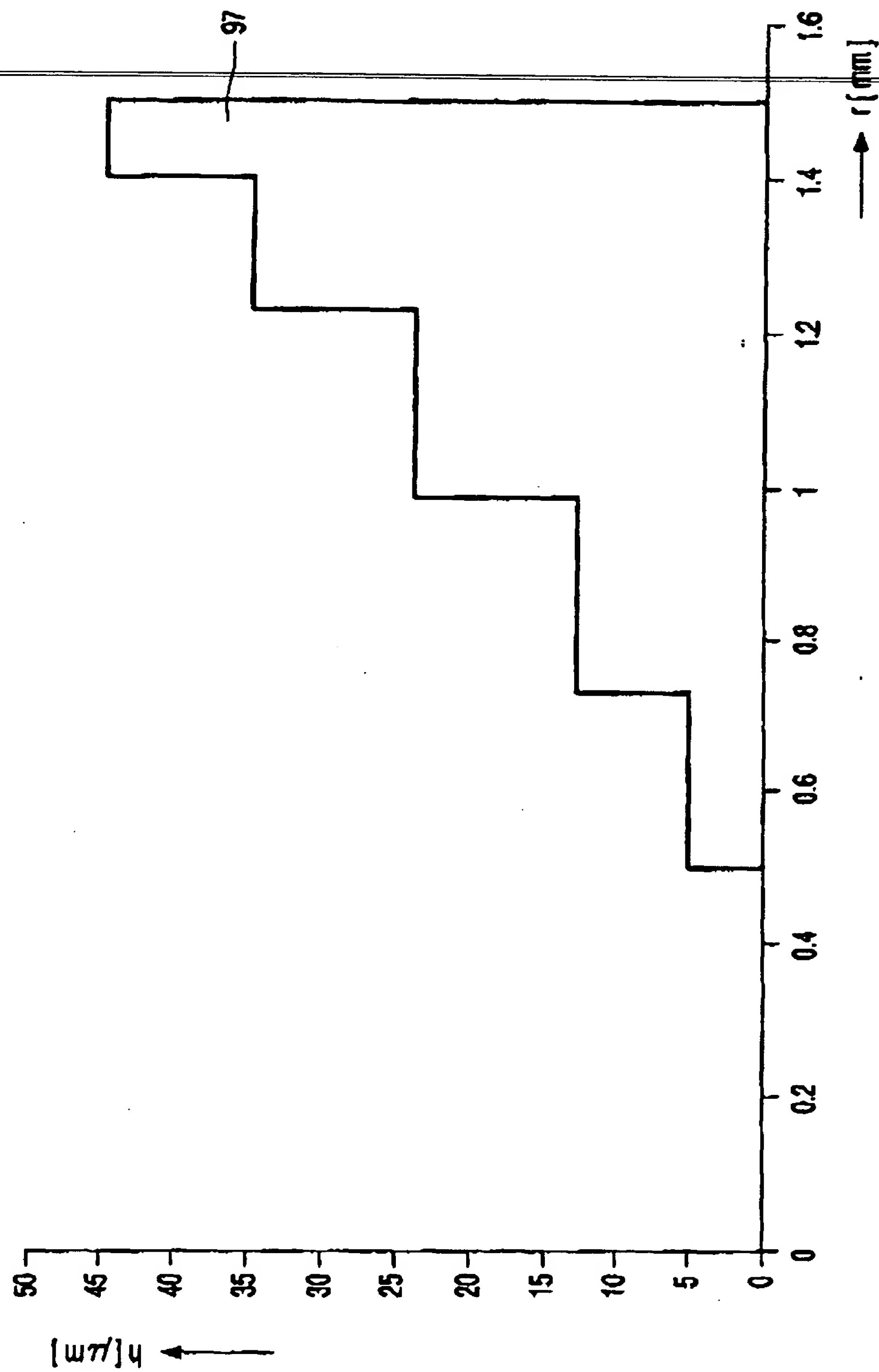


FIG. 6